EFFECTS OF INSECTICIDES ON POTATO LEAFHOPPERS *EMPOASCA FABAE* (HARRIS) AND ITS PREDATORS

by

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Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Entomology

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May, 1979

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ACKNOWLEDGEMENTS

I would like to express my gratitude first to Dr. Robert L. Pienkowski for his advice, help, and tireless interest at all stages of the work reported here. I am also grateful to Drs. D. G. Cochran and L. T. Kok for their advice and constructive criticism of this manuscript.

My thanks are due also to the staff and to the graduate students of the Entomology Department, who both contributed to an enjoyable visit to the United States and offered invaluable advice or assistance at various times during my studies.

Special appreciation is extended to Dr. D. E. Simonet for helping me start with this research and to Mr. R. Blakeslee for the field tests.

Finally, I wish to acknowledge Dr. R. D. Gordon of Systematic Entomology Laboratory, IBIII for identifying the predators collected.

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I. INTRODUCTION

The potato leafhopper, Empoasca fabae Harris (Homoptera: Cicadellidae) is an important pest of alfalfa in Virginia. A significant amount of research has been conducted on the biology, damage, dispersal, migration, and control of this pest. A bibliography on the potato leafhopper has been published by Gyrisco et al. (1978).

Control practices against the potato leafhopper include numerous methods which could be incorporated into an integrated pest management program. Cultural control, mechanical control, host plant resistance and selective use of pesticides have been employed to suppress potato leafhopper populations. However, research on biological control or the use of biological insecticides has not been extensive. These areas of research would be beneficial in an ecological approach to pest control.

The pest management approach utilizes all the pertinent scientific knowledge in order to provide effective and economical crop protection. Because many important agricultural pest species are often under heavy biotic pressures from parasites and predators, one of the most promising lines of research in pest management involves the integration of chemical and biological control.

The integrated control concept, as developed for use on crops that have a long growing season, such as alfalfa, assumes that the biological control elements can generally maintain the pest population levels below a specified economic threshold. If the pest density increases above the threshold, pesticides that are selective in action are used. Selective pesticides are those that exert more toxic effects on the target pest than on the beneficial species.

In the past, chemicals have provided the primary method of control against the potato leafhopper. With the growing pressures for economically efficient and environmentally safe pest management practices, more studies are needed to determine the exact effects of chemicals on the target as well as the non-target organism, and the environment as a whole.

This study details the effects of commonly used insecticides on the potato leafhopper and its predators in alfalfa. Included are three types of studies. First, the common predators of the potato leafhoppers in alfalfa were examined. An indirect assessment of predatory abilities of *Nabis americoferus* and *Orius insidiosis* on the eggs of the potato leafhopper was conducted. The nymphal and adult stages of the potato leafhopper were also exposed to the following predators: *Nabis americoferus*, *Chrysopa carnea*, *Hippodamia convergens*, and *Coccinella novemnotata*. A few authors have observed and described predation on the potato leafhopper by damsel bugs, lady beetles, and *O. insidiosis* but no quantitative assessment of predation at different growth stages has been published. Second, under field conditions, insecticides were tested to detect effects on the population of the potato leafhopper and the predators. Finally, toxicities of selected insecticides, expressed as LC_{50} were investigated under laboratory conditions.

These experiments were conducted in order to provide more precise information as to the predators of the potato leafhopper, and as to the selectivity of the registered insecticides. It is my hope that this information may lead to more efficient control of the potato leafhopper and more effective utilization of its predators.

II. LITERATURE REVIEW

A. Biology of the Potato Leafhopper

The leafhoppers are comprised of a very large group of species belonging to the family Cicadellidae which are of various forms, color, and sizes. There are 19 subfamilies of leafhoppers listed by Borror et al (1976). The potato leafhopper belongs to the subfamily Typlocylinae (Cicadellinae). Several species within the genus Empoasca are strikingly similar and may only be distinguished by genitalia characteristics. DeLong (1931) was the first to use the characteristics of the internal male genitalia and revised the systematics of the genus which clarified the taxonomic status of the potato leafhopper.

The potato leafhopper is known to have a wide variety of plant hosts. Poos and Wheeler (1943) reported that it has been collected from over 100 plant species and often reaches economic pest status on many fruits, vegetables, and forage crops. Feeding by the insect produces damage referred to as "tipburn", "hopperburn", or "alfalfa yellows". The damage is the result of deposition of a proteinaceous sheath material in the phloem and xylem of the plant at the time of feeding (Poos and Westover 1934). This feeding interferes with the normal physiology of the plant by mechanically plugging the tissues affected so that transport of food materials is impaired. The nature of damage was originally thought to be the result of a viral disease that could be induced in the laboratory by injecting macerated potato leafhopper into plant tissue (Eyer 1922) but other similar tests did not support this hypothesis. Newton et al. (1970) reported that females caused more severe injury than males, possibly because oviposition creates higher energy needs resulting in more feeding.

The potato leafhopper does not overwinter in the northern regions of the United States (DeLong and Caldwell 1935, Medler 1957, Decker and Cunningham 1968). Evidence suggests a spring migration from the Gulf states rather than an overwintering stage. A considerable amount of research has focused on weather conditions associated with dispersal and arrival of spring migrants in the northern United States (Decker 1959, Pienkowski and Medler 1964). Females withstand the trials of migration better than males (Medler et al. 1966) and this results in a predominance of fertilized, egg-laying females in the spring population. The possibility of a return migration to the south in the fall has not been investigated. Studies on insect migration presumed movements to be long distance and to and fro. However, this assumption has not yet been proven (Dingle 1972).

Documentations of environmental factors affecting the growth and development of potato leafhopper are abundant. The effects of cold temperature on the survival of potato leafhoppers in laboratory and field studies were reported by Decker and Cunningham (1967, 1968), and Decker and Maddox (1967). Kieckhefer and Medler (1964) reported that a 16:8 (L:D) photoperiod and 75°F were optimal for oviposition. Simonet (1978) found that at 23.9°C females laid eggs over a longer period and more eggs/female were observed. DeLong (1938) discovered no correlation between temperature and population growth of potato leafhopper on beans. A high relative humidity is favored by the insect (DeLong 1965, Decker and Cunningham 1967). Humidity was also important in defining the geographical boundaries of the potato leafhopper in the United States. Generally, they are found east of the 100th meridian at lower altitudes where rather high relative humidities prevail.

The reproductive capacity of the potato leafhopper has been investigated by some authors. DeLong (1938, 1971) reported that the oviposition rates range from 2.7 - 6.0 eggs/female/day. The differences were perhaps influenced by the environment. Simonet (1978) studied nymphal and adult morphometrics, sex ratios, and thermal requirements for oviposition. The results of his studies have led to a proposed classification of instars by head capsule measurements. Also, he indicated that sex-ratios favored males early in the oviposition period and favored females later, which closely agreed with the results obtained by Decker et al. (1971).

B. Control of the Potato Leafhopper

Numerous procedures have been employed to suppress the populations of potato leafhoppers in alfalfa. Cultural control was an early recommendation by Graber and Sprague (1933, 1935) and Jewett (1934) through delay of the first cutting of hay until the crop showed abundant bloom. Harvest operations will either kill or remove all the eggs and young nymphs. Other cultural control practices involve irrigation which could reduce potato leafhopper damage by decreasing plant stress (Wilson et al. 1955). Host plant resistance holds a great promise for the future as a management technique in alfalfa. This area of research is still active and could prove to be of considerable importance (Roof et al. 1976).

Threshold studies of this insect on soybeans have been published (Ogunlana and Pedigo 1974). When formulating threshold limits of potato leafhoppers, it is important to consider many factors including population density, stage of development, duration of feeding, host variety, host size, and environmental factors such as temperature and relative humidity. Poos (1942) stated that one potato leafhopper per sweep would cause significant damage within three weeks. It is now considered necessary to apply insecticides when one potato leafhopper per sweep* is collected in alfalfa less than 25.4 cm tall (Edwards 1974, Blair 1975).

C. Natural Enemies of Potato Leafhopper and Insecticides

Published information concerning the natural enemies of the potato leafhopper is relatively scarce. Gyrisco et al. (1978) conducted a survey on the literature of arthropods associated with alfalfa and observed that between 1910 and 1977, only 23 articles about the parasites and predators of potato leafhoppers were published.

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*A sweep is defined as a 180° motion employing a standard 38.1 cm net.

There are more published reports on predators than parasites of potato leafhoppers. Fenton (1918) studied the parasites of leafhoppers with special reference to the biology of the Anteoninae. Pimental (1973) surveyed the kinds and numbers of arthropods associated with an alfalfa community in New York state. In another study of arthropod fauna of alfalfa in New York, Wheeler (1974, 1977) classified predators as primary, secondary, and incidental. Primary predators are those that complete their life cycle on alfalfa; secondary predators are those whose adults took prey from the plants but bred elsewhere; and incidental predators are those not observed to capture prey on alfalfa. Field observations indicate that *O. insidiosis*, *N. americoferus*, *C. carnea*, *C. maculata*, and *L. lineolaris* prey on potato leafhopper. However, *H. convergens* was not observed feeding on potato leafhopper.

D. Insecticide Effects on Potato Leafhoppers and Its Predators

The effects of insecticide application on the population of leafhoppers have been documented by several authors (Hofmaster 1959, Granett and Reed 1960, Forsythe et al. 1962, Fahey et al. 1970, Judge et al. 1970, Koinzan and Pruess 1975, Simonet et al. 1978). In most cases, maximum population reductions were obtained 48 hours post treatment with some recovery 2 weeks after treatment. Similarly, the responses of beneficial arthropods in different field crops were studied intensively (Goodarzy and David 1958, Bartlett 1963, Yun and Ruppel 1964, Herne and Putman 1966, Dinkins et al. 1971, Bianco 1974, and Turnipseed et al. 1975). Johnson (1974) tested bacterial insecticides such as Dipel , Biotrol XK , and Thuricide on coccinellids and found no harmful effects.

The influence of insecticide application in relation to the stage of alfalfa growth was studied by Weires and Radcliffe (1974). They concluded that the use of stubble sprays on alfalfa appears to offer selectivity on beneficial species. Beneficial species tend to have greater mobility and disperse from the field following cutting while less mobile species remain -- e.g. immature of aphids, plant bugs, and leafhoppers. On the contrary, Rakickas and Watson (1974) observed that when full-grown alfalfa was cut, adults of _Nabis_, _Collops_, _Geocoris_, _Chrysopa_, reduviids, and coccinellids do not migrate to nearby fields.

Reports on response of alfalfa yield to insecticidal treatments are conflicting. Medler and Fisher (1953) reported yield increases of 38 - 300%, following various treatments which they attributed to potato leafhopper suppression. Other authors who reported similar yield increase were Weaver (1950), Moore (1959), Ellis and McEwen (1970), and Weires and Radcliffe (1974). On the contrary, Dondale (1972), Radcliffe et al. (1976), and Byers et al. (1977) obtained no significant yield increases following insecticidal treatments. Caution should be exercised in attempting to relate insecticidal treatments with yield because numerous factors interact in the creation of yield components. Factors such as stage of plant growth (Kouskolekas and Decker 1968), cultivars (Radcliffe et al. 1976), and fungicidal sprays (Wilcoxson and Bielenberg 1972) could influence and interact with the yields of the field tests. It is therefore important, that future studies should be undertaken to ellucidate the factors responsible for the observed yield increases.

Mortality caused directly by contact of a natural enemy with a toxicant should not only be documented in terms of the reductions in their numbers, but also degree of parasitism or predation in the field. Croft and Brown (1975) commented that while this may be helpful, it is usually impossible to distinguish between the direct effects and indirect effects caused by the destruction of the prey, hosts, competitors, or alternate food sources of the natural enemy population. A more precise and quantitative assessment of direct acute toxicity is the dosage-mortality relationship.

The result of a literature survey on insecticide dosage-mortality relationships affecting N. americoferus, O. insidiosis, C. carnea, H. convergens, and C. novemnotata is shown in Table 1. Figures for median lethal doses, deposits, or concentrations (LC_{50} or LD_{50}) from seven investigations with 2 species of coccinellids show an order of toxicity for the insecticides similar to that which had been deduced for O. insidiosis, C. carnea and N. americoferus. Taking the results as a whole, the more toxic insecticides to the mentioned predators are: parathion, methyl parathion, and azinphosmethyl. The less toxic insecticides are schradan, binapacryl, toxaphene, endrin, DDT, endosulfan, and chlorobenzilate.

Croft and Brown (1975) reported that predators are generally more tolerant to insecticides than are their prey. However, they reasoned that most of the predators represented in their studies were

Table 1

Susceptibility of predators to insecticides ranked in ascending order of LD_{50} or LC_{50}.

PREDATOR	STAGE TESTED	RANKED INSECTICIDES	BIOASSAY[a] METHOD	REFERENCE
Hippodamia convergens	Larvae	parathion, malathion, mevinphos, demeton, carbophenothion, schradan, nicotine	R	Bartlett (1958)
	Adult	methyl parathion, parathion, DDT, heptachlor, endrin, dieldrin	R	Burke (1959)
	Adult	dicrotophos, methyl parathion, phosphamidon, demeton, trichlorfon	T	Lingren and Ridgway (1967)
	Adult	parathion, malathion	R	Hamilton and Kieckhefer (1969)
	Adult	azinphosmethyl, parathion, carbaryl, diazinon, DDT, endosulfan, binapacryl	T	Moffitt et al. (1972)
	Adult	methyl parathion, carbaryl, malathion, toxaphene	R	Wilkinson et al. (1975)
Coccinella novemnotata	Adult	phosphamidon, demeton, azinphos-methyl, dimenthoate, Penncap M , carbaryl, phosmet, phosalone	D	Travis et al. (1978)

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[a] D = direct spray, R = exposure to residues, T = topical application.

Table 1 (cont.)

PREDATOR	STAGE TESTED	RANKED INSECTICIDES	BIOASSAY[a] METHOD	REFERENCE
Orius insidiosis	Adult	parathion, methyl parathion, malathion, aldrin, toxaphene, dieldrin, DDT	R	Burke (1959)
	Adult	methyl parathion, dicrotophos, trichlorfon, phosphamidon, demeton	R	Lingren and Ridgway (1967)
Chrysopa carnea	Larvae	phosphamidon, dicrotophos, methyl parathion, demeton, trichlorfon	T	Lingren and Ridgway (1967)
	Larvae	azinphosmethyl, carbaryl, ethion, chlorobenzilate	T	Lawrence (1974)
	Larvae	methyl parathion, carbaryl, toxaphene, malathion	R	Wilkinson et al. (1975)
	Larvae	methyl parathion, ethyl parathion, trichlorfon, curacron, methomyl, bolstar, dieldrin, acephate, permethrin, DDT, toxaphene, chlordimeform, endosulfan	R	Plapp and Bull (1978)

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[a] D = direct spray, R = exposure to residues, T = topical application.

Table 1 (cont.)

PREDATOR	STAGE TESTED	RANKED INSECTICIDES	BIOASSAY[a] METHOD	REFERENCE
Nabis americoferus	Adult	methyl parathion, carbaryl, malathion, toxaphene	R	Wilkinson et al. (1975)
	Adult	methyl parathion, dicrotophos, trichlorfon, phosphamidon, demelton	T	Lingren and Ridgway (1967)
	Adult	parathion, malathion	R	Hamilton and Kieckhefer (1969)

[a] D = direct spray, R = exposure to residues, T = topical application.

coccinellids, which are well known as being tolerant to a variety of insecticides. Among the other reasons cited for the above results were: (1) prey species were of pristine susceptibility, whereas predators were taken from localities which had been under insecticide pressure for some time or were populations actually suspected of having some tolerance; (2) many of the compounds with which they were tested had been chosen as being likely to be less toxic to the predators than to their prey.

III. PREDATION TESTS

Selected species of general predators were investigated to determine whether they are likely to prey on potato leafhoppers under field conditions. Predation tests were conducted using the various life stages of the potato leafhoppers and its predators.

A. Materials and Methods

1. Rearing and Handling of Test Insects

A colony of potato leafhoppers was maintained for this study. The cage housing the colony was equipped with glass on sides and top, measured 75 x 65 x 60 cm. Light and illumination was provided by two fluorescent bulbs suspended over the cage. The photoperiod was 10-12 hours and the temperature was 25-30°C. The colony was started by using field-collected adults. Broad bean, *Vicia faba* Linn., was used as the plant host. A relative humidity range of 60-100% was maintained with a daily water mist application. Host plants in the cage were replaced before complete wilting occurred. Purity of the colony was maintained by periodic removal of pea aphids, *Acyrtosiphon pisum* (Harris).

The predators used for this experiment were field collected from different alfalfa fields near Blacksburg, Virginia using a sweep net. Suspected predators that were collected and tested were lady beetles (*Hippodamia convergens*, *Coccinella novemnotata*), damsel bug (*Nabis americoferus*), green lacewing (*Chrysopa carnea*), pirate bug (*Orius* *insidiosis*) and tarnished plant bug (*Lygus lineolaris*).

2. Predation on Egg Stage of the Potato Leafhopper

An indirect method of determining egg predation was employed. Direct observation of predation of potato leafhopper eggs is rather difficult because the eggs are concealed in the xylem and phloem tissues. The number of potato leafhopper nymphs from cages with two sets of treatment (i.e. with and without predators) were counted and analyzed. Insects suspected of predatory behavior on eggs of potato leafhopper include *O. insidiosis*, and *N. americoferus* due to their piercing-sucking mouthparts. The egg predation tests using *O. insidiosis* and *N. americoferus* were conducted in the summer of 1977 and 1978 respectively. For these experiments, the following procedures were conducted.

Adult female potato leafhoppers were field collected and placed in egg predation cages. The cages were made of 50 dram vials containing excised broad bean stems placed in 3% sucrose solution. Experiments were conducted in an environmental chamber at 24°C with a 16:8 (L:D) photoperiod. Two female leafhoppers per cage were allowed to oviposit for a 24-hour period. After the 24-hour period, the potato leafhoppers were removed and the suspected predators (1 male and 1 female) were introduced. The leafhoppers upon being removed from one stem, were placed on second, third, etc., stems for 24 hours each. The predators were sequentially placed with the stems which had previously been exposed to the female leafhoppers. The predators were placed with each stem for 24 hours. Individual predators were always exposed to eggs from the same 2 leafhoppers. *O. insidiosis* were exposed to 3 series of stems containing eggs. *N. americoferus* were exposed to 5 series of stems containing eggs. Hatching nymphs were counted and used as an indication of the number of eggs laid. Comparative observations were made concerning hatching nymphs in cages where suspected predators were introduced and in control cages. Treatments were replicated eight times for *O. insidiosis* and seven times for *N. americoferus*. In analyzing data, Student's t tests were performed to compare the means of the two treatments.

3. Predation on Nymphal and Adult Stages of the Potato Leafhopper

A preliminary visual observation was made as to whether the different stages of lady beetles, damsel bug, and green lacewing would prey on second and third instar potato leafhopper. When predation occurred, a quantitative assessment was made of the predators' consumption capacity under limited searching requirements using closed chambers. This was accomplished by placing sets of five nymphs or adults in 100 x 15 mm petri dishes containing a single unifoliate broad bean leaf and introducing an individual predator. The potato leafhoppers were placed individually on the leaf surface using a camel-hair brush dipped in water. Each test was run for five days with daily observations on the number of consumed potato leafhoppers. Leafhoppers which were not consumed during a 24-hour period were replaced. Control petri dishes containing only potato leafhoppers were maintained. Leafhopper mortality in the control cages began to occur after five days, consequently observations could only be maintained for five-day periods.

A minimum of nine replications were performed in each test.

B. Results and Discussion

The egg predation tests using *O. insidiosis* and *N. americoferus* indicate that these insects are predaceous on the eggs of the potato leafhopper (Tables 2 and 3). Significant differences among treatments (with and without predators) were obtained using Student's t-test at 5% level of significance. It is rather difficult to compare the performance of *O. insidiosis* and *N. americoferus* because the tests were not conducted at the same time. However, results suggest that fewer potato leafhopper nymphs emerge following exposure to *O. insidiosis* than *N. americoferus*. Discretion should be used in drawing analogies between these results in the laboratory and the effectiveness of the predators in the field. The tests presented here are only relative to egg predation under laboratory conditions and results require further field and laboratory confirmation. Also, these tests used broad beans as the plant host instead of alfalfa, and should be repeated using alfalfa as the plant substrate. This represents only an initial attempt to measure searching and feeding potentials of the local predatory arthropods against the eggs of this pest. However, despite the experimental conditions, the performance of the species in the cages probably reflects their relative status as egg predators in the field.

Tables 4 and 5 report the efficacy of different life stages of the predators with limited searching requirements. The tests indicate

Table 2

EGG PREDATION TEST: Comparison of average number of emerging potato leafhopper nymphs per cage with and without *Orius insidiosis*.

TREATMENTS[a]	SEQUENTIAL 24 HOUR FEEDING PERIODS BY THE SAME PREDATORS		
	24[b]	48[b]	72[b]
With *O. insidiosis*	0.88	0.25	0
Without *O. insidiosis*	3.50	3.17	1.0

[a] Replicated eight times.

[b] Significantly different at 5% level using Student's t-test.

Table 3

EGG PREDATION TEST: Comparison of average number of emerging potato leafhopper nymphs per cage with and without *Nabis americoferus*.

	SEQUENTIAL 24 HOUR FEEDING PERIODS BY THE SAME PREDATORS				
TREATMENTS[a]	24[b]	48[b]	72[b]	96[b]	120[b]
With *N. americoferus*	3.17	0.50	1.00	0.33	0.17
Without *N. americoferus*	8.8 3	3.67	2.17	1.17	2.00

[a] Replicated seven times.

[b] Significantly different at 5% level using Student's t-test.

Table 4

Comparison of average daily consumption of potato leafhopper nymphs by various predators[a].

PREDATOR	AVERAGE DAILY CONSUMPTION[b]	% EFFICIENCY[c]
Hippodamia convergens (adult)	2.63 ± 0.16	53%
Hippodamia convergens (larva)	3.00 ± 0.28	60%
Coccinella novemnotata (adult)	2.23 ± 0.20	45%
Coccinella novemnotata (larva)	2.63 ± 0.21	53%
Chrysopa carnea (adult)	0.42 ± 0.09	8%
Chrysopa carnea (larva)	2.20 ± 0.35	44%
Nabis americoferus (adult)	2.18 ± 0.24	44%

[a] Average of 9 or more replicates; both sexes used in roughly equal numbers.

[b] Mean ± Standard Error.

[c] Based on 5 days of test.

Table 5

Comparison of average daily consumption of potato leafhopper adults by various predators[a].

PREDATOR	AVERAGE DAILY CONSUMPTION[b]	% EFFICIENCY[c]
Hippodamia _convergens_ (adult)	3.22 ± 0.21	64%
Hippodamia _convergens_ (larva)	2.20 ± 0.19	44%
Coccinella _novemnotata_ (adult)	2.69 ± 0.16	54%
Coccinella _novemnotata_ (larva)	2.20 ± 0.30	44%
Chrysopa _carnea_ (adult)	2.10 ± 0.18	42%
Chrysopa _carnea_ (larva)	1.98 ± 0.19	40%
Nabis _americoferus_ (adult)	1.90 ± 0.03	38%

[a] Average of 9 or more replicates; both sexes used in roughly equal numbers.

[b] Mean ± Standard Error.

[c] Based on 5 days of test.

that immature stages are more efficient predators of the potato leafhopper nymphs while adult predators are more efficient predators of adults of the potato leafhopper. A theoretical value of the predator's efficiency was obtained by dividing the total consumption for five days by the maximum prey available. This does not take into account other competing food sources such as the pea aphid which would be available under field conditions.

Adults and larvae of _H_. _convergens_ are generally effective predators of the potato leafhopper nymphs and adults. Assuming that some of the other coccinellid predators (which were not studied in detail) were capable of consuming potato leafhoppers at a rate comparable to convergent lady beetles, it is likely that the coccinellids were the most effective predators. Adults and larvae of _C_. _novemnotata_ are not as effective as the convergent lady beetles.

Following the coccinellids in importance were the larva of green lacewing and adult damsel bugs which were approximately equal. The _Chrysopa_ larva consumed a significant number of leafhoppers per individual, but unfortunately were seldom numerous in the field. If their numbers could be increased, _Chrysopa_ would become highly valuable in destroying potato leafhoppers. It appears that under field situations, _Nabis_ will be more important than _Chrysopa_ because they are more abundant in the field. Wheeler's (1974) observation of _L_. _lineolaris_ feeding on nymphs of potato leafhoppers was not confirmed in this experiment.

There appears a considerable difference in the consumption capacity of predators as the prey species changes. Goodarzy and Davis

(1958) reported that the average daily consumption on apterous spotted alfalfa aphids by a single adult of H. convergens, N. alternatus, and O. tristicolor were 32.9, 5.3, and 1.4 respectively. Aside from variation due to prey species, predation also depends on predator's sex, developmental stage, and temperature (Crocker et al. 1975). In this experiment, since certain variables such as alternate food in an unlimited searching requirements did not receive consideration, caution again should be exercised in projecting the results into natural field conditions; however, the differences in efficacy measured provide considerable insight into the feeding and searching behavior of the predators studied.

Although more careful studies are needed, predation of species tested were shown on potato leafhoppers. Blackman (1968) stated that if an attacker is observed under laboratory conditions to consume part or all of a victim, and repeats this behavior as often as new victims are supplied, this behavior is good evidence that the attacker is predaceous on the victim under natural conditions, provided that the 2 normally come into physical contact with one another in the field.

IV. FIELD INSECTICIDE TESTS

A. Materials and Methods

Two field tests, one in summer of 1977 and one in summer of 1978, were conducted to determine the influence of insecticides on populations of potato leafhoppers and predators in alfalfa. A listing of the insecticides tested can be found in Table 6. Both were conducted in the same field of Saranac AR alfalfa in Montgomery County, Virginia. Plots were 40 feet (12.2 m) by 40 feet (12.2 m) and arranged in randomized block design. Each field test included untreated control plots. Treatments were replicated four times. Insecticides were applied on Aug. 4, 1977 and July 6, 1978. A hand-carried compressed air sprayer discharging at the rate of 20 gallons per acre (40 psi) was used. Drift was minimized by spraying on nearly windless days. In both tests, insecticides were applied between 11:00 A. M. and 1:00 P. M.

Samples of potato leafhoppers and predators were taken at 48 hours, 1 week, and 2 week intervals following treatment. Samples were taken using a 180° sweep with a sweep net. Two sets of 20 sweeps from each plot were taken. Collected insects from sweep nets were placed in bags labelled according to the treatment and returned to the laboratory for counting. In addition to post-treatment counts, ten pre-treatment samples from the field area were taken for both tests. Yield and green weight were taken from the 1977 test on August 25 at 25% bloom with a Flail forage harvester using a 3 feet (.914 m) by 20 feet (6.1 m) swath per plot. Percent dry matter was also measured.

Table 6

Insecticides used in the foliar spray tests and LC_{50} determinations.

OFFICIAL COMMON NAME	TRADE NAME	ACTIVE INGREDIENT	FIELD RATE LBS. AI/A	FORMULATIONS
carbaryl	Sevin	1-naphthyl N-methylcarbamate	1.0 lb	50% W.P.
carbofuran	Furadan	2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate	0.25, 0.50, 1.00 lb	4 F
methomyl	Lannate	methyl-N[(methylcarbamoyethyl) oxy] thioacetimidate	1.0 lb	1.8 lbs/gal L
malathion	Cythion	0,0-dimethyl S-(1,2,-dicarbethoxy-ethyl) phosphorodithionate	1.0 lb	50% E.C.
azinphosmethyl	Guthion	0,0-dimethyl S-[4-oxo-1,2,3, benzo-thiazin-3-(4,4)-ylmethyl phosphorodithioate	0.5 lb	2 lbs/gal E.C.
methidathion	Supracide	0,0-dimethyl phosphorodithioate, S-ester	0.5 lb	2 lbs/gal E.C.
phosmet	Imidan	S-[(1,3-dihydro-1,3-dioxo-2-H-isoindol-2-yl)methyl]0,0-dimethyl phosphorodithioate	1.0 lb	50% W.P.
methoxychlor	Marlate	2,2-bis-(p-methoxyphenyl)-1,1,1-trichloroethane	0.5 lb	50% W.P.

In order to facilitate statistical analysis of the data, the total number of potato leafhoppers and predators counted in each sample were transformed by Log(X + 1). Data were analyzed using analysis of variance. Comparisons of significant differences between means were made using Duncan's multiple range test. No statistical analysis was made for pre-treatment counts.

B. Results and Discussion

1. Effects on Potato Leafhoppers and Tarnished Plant Bugs

The pre-treatment counts indicate that there were more leafhoppers in the 1978 test than in the 1977 test (Tables 7 and 8). In both tests, significant control was provided by most of the chemicals over the control. However, a gradual population recovery was obtained one week and two weeks after treatment. There were statistical differences in efficacy among treatments on each date. For the 1977 test, carbofuran at 1.0 lb AI/A was the overall most effective insecticide while methoxychlor was the least effective. The problem with methoxychlor was probably related to clogging of nozzles while spraying a wettable powder formulation. For the 1978 test, the insecticides provided effective control except carbaryl two days after treatment and malathion one week and two weeks after treatment. There was a decline in the population of leafhopper from the control plot 2 days after treatment which could possibly be because of migration.

The responses of _L. lineolaris_ to insecticides are shown in Tables 9 and 10. For the 1977 test, significant differences were

Table 7

Insecticide effect on population of *Empoasca fabae* Harris[a] (1977 Test).

TREATMENTS (IN LB. AI/A)	PRE-TREAT COUNT[b] AUG. 4	POST-TREATMENT COUNT[c] AUG. 6	AUG. 13	AUG. 18
carbofuran, 1.0	35.88	0.00 c	1.33 c	1.68 d
carbofuran, 0.5	35.88	0.33 c	2.66 b	5.35 bc
carbofuran, 0.25	35.88	0.17 c	2.17 b	6.17 bc
methidathion, 0.5	35.88	0.33 c	3.51 b	4.17 c
carbaryl, 1.0	35.88	0.51 c	3.00 b	7.35 bc
phosmet, 1.0	35.88	0.84 c	2.17 b	6.66 bc
malathion, 1.0	35.88	0.84 c	4.00 b	10.17 bc
methoxychlor, 0.5	35.88	7.00 ab	14.17 a	13.17 ab
control	35.88	9.00 a	15.35 a	22.35 a

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[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 8

Insecticide effect on *Empoasca fabae* Harris[a] (1978 Test).

TREATMENT (IN LBS AI/A)	PRE-TREAT COUNT[b] JULY 6	POST-TREATMENT COUNT[c] JULY 8	JULY 13	JULY 18
carbofuran, 0.5	243.6	0.00 c	18.75 bc	35.50 bc
azinphosmethyl, 0.5	243.6	0.00 c	19.75 b	34.25 bc
phosmet, 1.0	243.6	0.875 c	15.75 c	28.75 c
methomyl, 1.0	243.6	0.00 c	16.00 c	31.75 bc
malathion, 1.0	243.6	0.375 c	41.75 ab	59.75 ab
carbaryl, 1.0	243.6	7.00 b	17.75 bc	23.75 c
methidathion, 0.5	243.6	0.25 c	19.25 bc	34.50 bc
control	243.6	14.375 a	63.00 a	95.00 a

[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 9

Insecticide effect on population of *Lygus lineolaris*[a] (1977 Test).

TREATMENT (IN LB AI/A)	PRE-TREAT COUNT[b] AUG. 4	POST-TREATMENT COUNT[c] AUG. 6	AUG. 13	AUG. 18
carbofuran, 1.0	16.64	0.84 b	1.51 d	5.67 ab
carbofuran, 0.5	16.64	0.67 b	2.00 cd	6.84 a
carbofuran, 0.25	16.64	0.33 b	2.84 bcd	4.51 ab
methidathion, 0.5	16.64	0.84 b	4.84 ab	6.00 ab
carbaryl, 1.0	16.64	0.67 b	6.51 a	4.33 ab
phosmet, 1.0	16.64	0.51 b	3.51 abc	4.00 ab
malathion, 1.0	16.64	1.51 ab	6.84 a	3.00 b
methoxychlor, 0.5	16.64	3.67 a	5.33 ab	3.84 ab
control	16.64	3.67 a	4.83 ab	5.00 ab

[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 10

Insecticide effect on population of _Lygus lineolaris_[a] (1978 Test).

TREATMENTS (IN LB AI/A)	PRE-TREAT COUNT[b] JULY 6	POST-TREATMENT COUNT[c] JULY 8	JULY 13	JULY 18
carbofuran, 0.5	45.28	1.63 c	7.75 a	13.50 a
azinphosmethyl, 0.5	45.28	2.75 c	9.00 a	16.00 a
phosmet, 1.0	45.28	6.25 b	10.50 a	16.00 a
methomyl, 1.0	45.28	0.25 d	8.00 a	12.25 a
malathion, 1.0	45.28	2.38 c	6.50 a	8.00 a
carbaryl, 1.0	45.28	8.25 b	9.50 a	14.50 a
methidathion, 0.5	45.28	2.13 c	9.25 a	11.75 a
control	45.28	12.00 a	10.25 a	13.75 a

[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

obtained between the insecticides and control. Malathion and methoxychlor provided good control two days after treatment. It was difficult to single out an insecticide at one week and two weeks after treatment because several chemicals were not different from each other. For the 1978 test, significant differences among treatments were obtained only at 2 days after treatment. Methomyl was the most effective while phosmet and carbaryl did not provide sufficient control.

2. Effects on Entomophagous Insects

Populations of common entomophagous insects before and after insecticide treatment for the two tests (1977 and 1978) are shown in Tables 11-18. There were more predators in 1978 than 1977.

The coccinellids (primarily *H. convergens* and *C. novemnotata*) were adversely affected by some insecticides following treatments. For the 1977 test (Table 11), no differences among treatments were obtained two days after treatment. Two weeks after treatment, carbaryl and malathion did not significantly reduce coccinellids' population. For the 1978 test (Table 12), there were also no statistical differences two days after treatment. Carbaryl was effective in protecting coccinellids one week and two weeks after treatment.

The responses of *N. americoferus* population to chemicals are presented in Tables 13 and 14. For the 1977 test, methoxychlor did not reduce the population of the nabids. For the 1978 test, several chemicals were not different from each other. No statistical differences were observed at one week and two weeks after treatment. The results obtained from the use of carbaryl do not confirm the findings

Table 11

Insecticide effect on population of coccinellids[a] (1977 Test).

TREATMENTS (IN LB AI/A)	PRE-TREAT COUNT[b] AUG. 4	POST-TREATMENT COUNT[c] AUG. 6	AUG. 13	AUG. 18
carbofuran, 1.0	1.96	0.00 a	0.66 ab	0.66 cd
carbofuran, 0.5	1.96	0.33 a	0.33 ab	0.17 d
carbofuran, 0.25	1.96	0.17 a	0.17 b	1.00 cd
methidathion, 0.5	1.96	0.33 a	0.00 b	1.00 cd
carbaryl, 1.0	1.96	0.33 a	1.00 a	4.00 a
phosmet, 1.0	1.96	0.51 a	0.33 ab	0.33 d
malathion, 1.0	1.96	0.33 a	0.33 ab	3.17 ab
control	1.96	0.51 a	0.51 ab	1.67 bc

[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 12

Insecticide effect on population of coccinellids[a] (1978 Test).

TREATMENTS (IN LB AI/A)	PRE-TREAT COUNT[b] JULY 6	POST-TREATMENT COUNT[c] JULY 8	JULY 13	JULY 18
carbofuran, 0.5	13.6	0.125 b	1.00 c	1.50 c
azinphosmethyl, 0.5	13.6	0.125 b	3.25 bc	4.25 b
phosmet, 1.0	13.6	0.50 b	2.75 c	4.00 bc
methomyl, 1.0	13.6	0.25 b	2.25 c	2.75 bc
malathion, 1.0	13.6	0.125 b	2.50 c	4.50 b
carbaryl, 1.0	13.6	0.50 b	9.00 a	12.75 a
methidathion, 0.5	13.6	0.50 b	2.50 c	3.00 bc
control	13.6	3.125 a	8.50 a	12.75 a

[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 13

Insecticide effect on population of *Nabis americoferus*[a] (1977 Test).

TREATMENTS (IN LB AI/A)	PRE-TREAT COUNT[b] AUG. 4	POST-TREATMENT COUNT[c] AUG. 6	AUG. 13	AUG. 18
carbofuran, 1.0	5.32	0.00 d	0.51 d	2.17 a
carbofuran, 0.5	5.32	0.00 d	1.67 cd	0.33 a
carbofuran, 0.25	5.32	0.00 d	1.33 cd	0.54 a
methidathion, 0.5	5.32	1.33 bc	2.17 bcd	0.51 a
carbaryl, 1.0	5.32	0.84 cd	2.50 abc	0.84 a
phosmet, 1.0	5.32	2.51 b	2.60 abc	0.67 a
malathion, 1.0	5.32	2.67 b	2.17 bcd	0.51 a
methoxychlor, 0.5	5.32	7.33 a	5.33 a	2.00 a
control	5.32	6.17 a	4.33 a	1.84 a

[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 14

Insecticide effect on population of *Nabis americoferus*[a] (1978 Test).

TREATMENTS (IN LB AI/A)	PRE-TREAT COUNT[b] JULY 6	POST-TREATMENT COUNT[c] JULY 8	JULY 13	JULY 19
carbofuran, 0.5	14.8	0.625 cd	0.75 a	1.00 a
azinphosmethyl, 0.5	14.8	1.875 bc	1.25 a	1.75 a
phosmet, 1.0	14.8	2.75 b	4.75 a	1.25 a
methomyl, 1.0	14.8	0.00 d	2.50 a	1.50 a
malathion, 1.0	14.8	1.625 bc	1.00 a	1.25 a
carbaryl, 1.0	14.8	2.625 b	.75 a	2.50 a
methidathion, 0.5	14.8	1.375 bc	1.00 a	1.00 a
control	14.8	5.00 a	2.75 a	3.25 a

[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

of Turnipseed et al. (1975) who stated that the survival of nabids was excellent 48 hours post treatment with carbaryl. The results obtained agree with numerous authors who have claimed carbaryl to be disruptive to nabids (Bartlett 1963, Yun and Ruppell 1964, Herne and Putman 1966, Colburn and Asquith 1974, and Bianco 1974). The control plots showed reduction in nabids which could possibly be due to migration.

The most abundant predator in the field during the two summers of field tests was _O. insidiosis_. Results suggest that several chemicals were not different from each other and that it is difficult to single out an insecticide as the most effective or least effective (Tables 15 and 16).

The responses of _C. carnea_ population to chemicals are presented in Tables 17 and 18. For the 1977 test, no differences among treatments were observed for each data. However, statistical differences were observed at two weeks after treatment for the 1978 test. The author does not offer an explanation for the observed difference. There are conflicting results in published reports about the response of _C. carnea_ to insecticides. Herne and Putman (1966), Dinkins et al. (1971), and Summers et al. (1975) all report favorable response to insecticides. On the other hand, Bartlett (1964) and Bianco (1974) report detrimental response to insecticides.

Table 19 shows the yield and percent dry matter obtained during the 1977 test with various insecticidal treatments. There were no statistical differences among treatments.

All the data presented demonstrate that certain treatments with insecticides are capable of markedly reducing groups of beneficial

Table 15

Insecticide effect on population of *Orius insidiosis*[a] (1977 Test).

TREATMENT	PRE-TREAT COUNT[b]	POST-TREATMENT COUNT[c]		
(IN LB AI/A)	AUG. 4	AUG. 6	AUG. 13	AUG. 18
carbofuran, 1.0	11.2	1.00 bc	1.00 c	3.51 bc
carbofuran, 0.5	11.2	0.51 c	2.66 bc	6.17 ab
carbofuran, 0.25	11.2	1.51 abc	2.84 bc	3.33 abc
methidathion, 0.5	11.2	0.51 c	2.66 bc	3.84 abc
carbaryl, 1.0	11.2	1.33 abc	2.66 bc	4.51 abc
phosmet, 1.0	11.2	2.33 ab	3.17 bc	3.67 abc
malathion, 1.0	11.2	2.17 ab	4.35 b	1.84 c
methoxychlor, 0.5	11.2	1.67 abc	5.17 ab	2.33 c
control	11.2	2.84 a	10.50 a	6.66 a

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[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 16

Insecticide effect on population of <u>Orius insidiosis</u>[a] (1978 Test).

TREATMENTS (IN LB AI/A)	PRE-TREAT COUNT[b] JULY 6	POST-TREATMENT COUNT[c] JULY 8	JULY 13	JULY 18
carbofuran, 0.5	11.2	0.125 b	9.50 abc	15.75 a
azinphosmethyl, 0.5	11.2	0.75 b	7.50 c	11.75 a
phosmet, 1.0	11.2	1.25 b	11.75 ab	14.25 a
methomyl, 1.0	11.2	0.125 b	9.50 abc	13.50 a
malathion, 1.0	11.2	0.875 b	14.25 a	11.50 a
carbaryl, 1.0	11.2	5.625 a	7.75 bc	8.50 a
methidathion, 0.5	11.2	1.375 b	9.25 abc	13.25 a
control	11.2	4.75 a	13.25 a	15.00 a

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[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 17

Insecticide effect on population of <u>Chrysopa carnea</u>[a] (1977 Test).

TREATMENT (IN LB AI/A)	PRE-TREAT COUNT[b] AUG. 4	POST-TREATMENT COUNT[c] AUG. 6	AUG. 13	AUG. 18
carbofuran, 1.0	0.28	0.51 a	0.33 a	0.00 a
carbofuran, 0.5	0.28	0.00 a	0.00 a	0.00 a
carbofuran, 0.25	0.28	0.00 a	0.00 a	0.00 a
methidathion, 0.5	0.28	0.67 a	0.00 a	0.17 a
carbaryl, 1.0	0.28	0.33 a	0.00 a	0.17 a
phosmet, 1.0	0.28	0.51 a	0.00 s	0.17 a
malathion, 1.0	0.28	0.51 a	0.00 a	0.00 a
methoxychlor, 0.5	0.28	0.67 a	0.33 a	0.17 a
control	0.28	0.17 a	0.17 a	0.00 a

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[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 18

Insecticide effect on population of <u>Chrysopa carnea</u>[a] (1978 Test).

TREATMENTS (IN LB AI/A)	PRE-TREAT COUNT[b] JULY 6	POST-TREATMENT COUNT[c] JULY 8	JULY 13	JULY 18
carbofuran, 0.5	5.2	0.00 b	0.75 a	1.00 b
azinphosmethyl, 0.5	5.2	0.00 b	0.75 a	1.25 b
phosmet, 1.0	5.2	0.00 b	0.75 a	1.50 b
methomyl, 1.0	5.2	0.00 b	0.50 a	0.25 b
malathion, 1.0	5.2	0.25 b	0.75 a	1.25 b
carbaryl, 1.0	5.2	0.00 b	5.00 a	8.5 a
methidathion, 0.5	5.2	0.625 b	0.75 a	0.75 b
control	5.2	3.125 a	5.00 a	6.00 a

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[a] Insect counts per 40 sweeps.

[b] Average of total field plots.

[c] Means in a given column not followed by the same letter are significantly different ($P < 0.05$) according to Duncan's multiple range test.

Table 19

Effects of insecticides on yield and percent dry matter of alfalfa (1977 Test).

TREATMENTS (IN LB AI/A)	YIELD LBS/A	PERCENT DRY MATTER
carbofuran, 1.0	12,858	22.29
carbofuran, 0.5	13,131	22.10
carbofuran, 0.25	13,350	23.80
methidathion, 0.5	13,713	22.99
carbaryl, 1.0	14,132	22.88
phosmet, 1.0	15,950	25.43
malathion, 1.0	13,113	23.94
methoxychlor, 0.5	13,222	24.62
control	12,076	25.84

No significant differences ($P > 0.01$).

arthropods. However, the mechanisms by which these species are affected have not yet been clearly defined. They may feed on plant sap, pollen or plant exudates from treated plants; they may be affected by toxic residues on plant surfaces; they may feed on plant feeding pests which have accumulated insecticides in their bodies; and/or they may lack food because their hosts have been destroyed by insecticides (Ridgway et al. 1967).

Different species are likely to be affected in different ways. For instance, York (1944) indicated Geocoris feeds on plants to obtain moisture, and recent studies with radioisotopes indicated that Nabis also feed directly on cotton plants (Ridgway et al. 1967). Ahmed et al. (1954) reported that larvae of 3 species of Syrphidae were readily killed when they were fed aphids that had fed on leaves treated with systemic insecticides. However, when similar aphids were fed to 5 species of coccinellids and 2 species of Chrysopa, mortality rates varied considerably.

In summary, there are various complications that may arise during studies of the effects of insecticides on entomophagous insects. Some of these were discussed by van den Bosch et al. (1956). A reduction in the population density of the entomophagous insects is difficult to interpret because it may be due to (1) direct insecticide induced mortality, (2) feeding on the insecticide-affected hosts, or (3) starvation or migration after the host species has been eliminated. Also, when plot sizes are small, migration among plots may occur. In the foliar sprayed field test conducted, it is, therefore, difficult to pinpoint which of the factors mentioned was the major factor.

It is highly probable that different predatory species respond differently and should be studied individually.

V. LABORATORY TOXICITY TESTS

A. Materials and Methods

Busvine (1971) has reviewed in considerable detail the different methods by which insects may be exposed to various insecticide compounds for toxicological studies. In this experiment, it was felt necessary that a similar technique be used to determine the toxicity of selected insecticides to potato leafhoppers and predators. Several techniques were initially employed until a satisfactory method was found for all insects treated. Initial tests utilized the topical method. Excessive mortality of potato leafhoppers resulted from the solvent. The injection method had the disadvantage of a more time-consuming technique. It also does not show differential toxicity resulting from cuticle penetration. The immersion technique with acetone as the solvent was used. However, high mortality of untreated control samples was observed. Finally, the immersion technique with distilled water as the solvent was tried and worked well for all the tested insects.

The insects tested were adults and mixed-sex populations of potato leafhoppers, _Nabis americoferus_, and tarnished plant bugs. Toxicity data for lady beetles, green lacewings, and _Orius insidiosis_ have been reported in the literature (Table 1). Twenty insects were used per dose treatment with four replicates. Each replicate included an untreated control. The potato leafhoppers used for this experiment were mainly from the laboratory colony. In some tests, however, field collection of insects was necessary. Collection was from fields which had not been sprayed with insecticides.

A quantity of each insecticide was carefully measured and dissolved in distilled water to make up a master solution of known strength. Measured proportions of this master solution were then diluted to make up a series of solutions for the treatment of each species. The master solution and its diluted fractions were always made up immediately before use.

B. The Treatment Procedure

Application of various insecticides was accomplished by first knocking down the insects with carbon dioxide. Each anesthetized insect was carefully picked up by its legs using a pointed forceps and immersed for two seconds in the insecticide of known concentration. After immersion, the insects were placed on absorbent paper to absorb excess insecticide. The treated insects were placed in observation jars and the percentage mortality at each dosage level noted 24 hours after treatment. The 24-hour period proved to be an adequate time interval after preliminary observations indicated that mortality 24 and 48 hours after treatment was not significantly different. All of the treatments were made at approximately the same time each day.

Observation jars were provided with excised alfalfa stems to provide moisture during the observation period. They were maintained at 23°C.

C. Statistical Analysis

All data were analyzed by computer. The 1976 Statistical Analysis System (SAS 76) Probit Procedure was employed (Barr et al. 1976). Fiducial limits for the LC_{50} were calculated at the 95% confidence level from the computed variance using the following formula (Busvine 1971):

$$m_1 m_2 = m \pm 1.96\sqrt{v}$$

where v equals the variance for the LC_{50}, m equals the LC_{50} and m_1 and m_2 are lower and upper limits of LC_{50}.

D. Results and Discussion

The LC_{50} values, along with the 95% confidence intervals, regression coefficient equation and chi-square probability for E. fabae, L. lineolaris, and N. americoferus are presented in Tables 20, 21, and 22, respectively.

The response of E. fabae adults to treatment with the different insecticides (Table 20 and Fig. 1) varied with LC_{50}'s ranging from 8.16 (methidathion) to 41.32 (malathion) parts per million. There appeared to be no trend in the toxicities of organophosphates and carbamates to potato leafhoppers. The chi-square values indicated that there was no significant heterogeneity among the insect populations tested at the 5% level.

Table 21 and Fig. 2 show the response of L. lineolaris adults to insecticide treatments. Carbofuran, a carbamate was the most toxic

Table 20

Median lethal concentrations of insecticides tested against E. *fabae*.[a]

INSECTICIDE[b]	LC_{50} (PPM)	95% FIDUCIAL LIMITS	REGRESSION EQUATION	PROBABILITY > χ^2
methidathion (OP)	8.16	5.39 - 10.59	$y = 4.46 + 0.07x$	0.62
azinphosmethyl (OP)	8.99	6.76 - 11.03	$y = 4.33 + 0.07x$	0.13
carbofuran (C)	10.29	5.06 - 15.52	$y = 4.55 + 0.04x$	0.15
methomyl (C)	12.69	0.00 - 36.57	$y = 4.37 + 0.05x$	0.10
carbaryl (C)	15.38	6.23 - 22.43	$y = 4.46 + 0.04x$	0.15
malathion (OP)	41.32	31.89 - 50.07	$y = 4.37 + 0.02x$	0.19

[a] Arranged in descending order of toxicity.

[b] OP = organophosphate; C = carbamates.

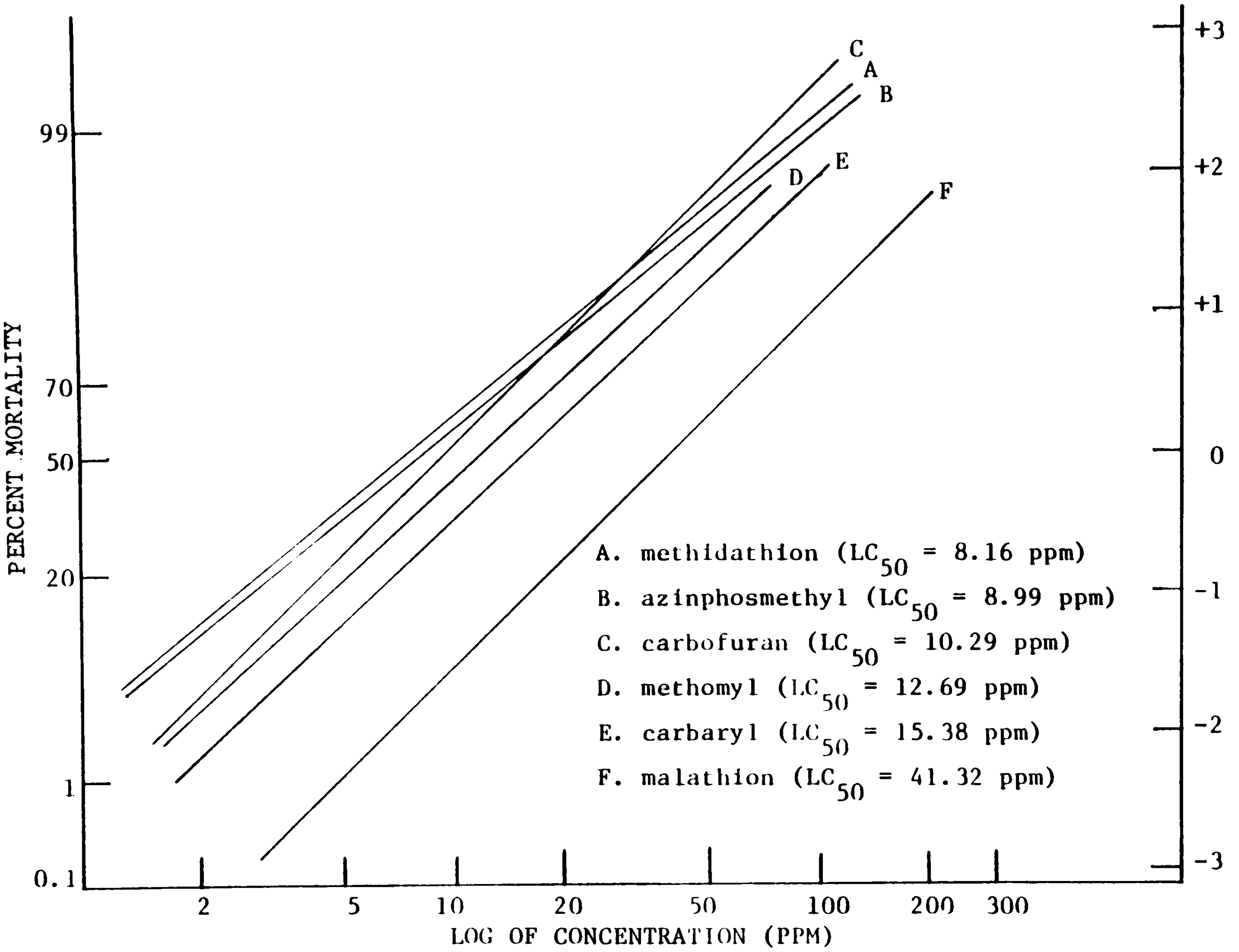

Figure 1. Response of mixed-sex populations of *E. fabae* to insecticides.

Table 21

Median lethal concentrations of insecticides tested against *L. lineolaris*.[a]

INSECTICIDE[b]	LC_{50} (PPM)	95% FIDUCIAL LIMITS	REGRESSION EQUATION	PROBABILITY > χ^2
carbofuran (C)	5.50	4.15 - 6.87	y = 4.27 + 0.13x	0.53
methidathion (OP)	12.00	8.36 - 15.24	y = 4.32 + 0.06x	0.14
methomyl (C)	16.42	12.92 - 19.74	y = 4.12 + 0.05x	0.25
malathion (OP)	68.08	53.06 - 77.58	y = 4.20 + 0.01x	0.11
azinphosmethyl (OP)	68.35	56.13 - 80.99	y = 3.92 + 0.02x	0.77
carbaryl (C)	73.27	54.47 - 104.01	y = 3.65 + 0.02x	0.10

[a] Arranged in descending order of toxicity.

[b] OP = organophosphates; C = carbamates.

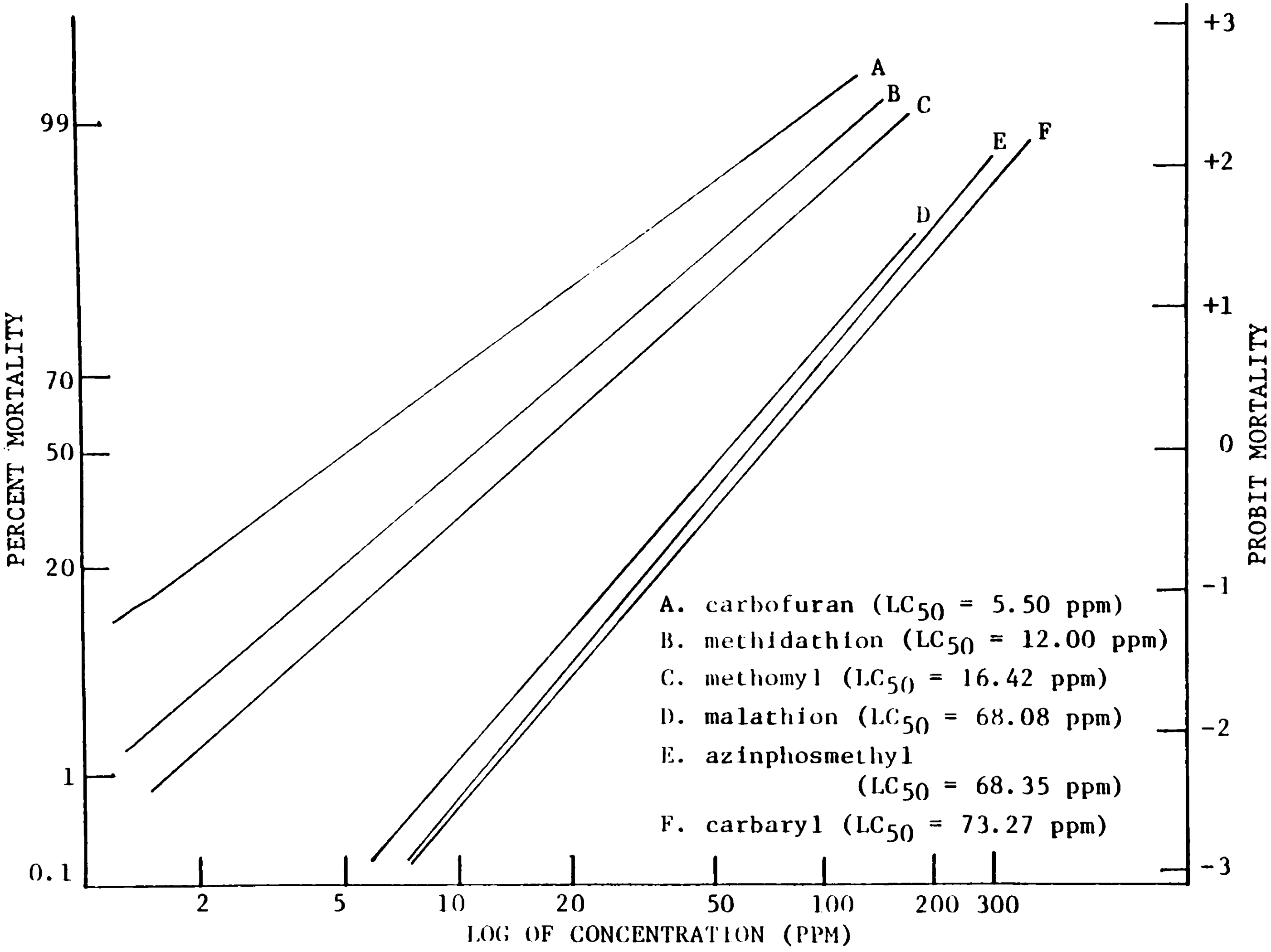

Figure 2. Response of mixed-sex populations of *L. lineolaris* to insecticides.

(LC_{50} = 5.50 PPM) while carbaryl, which is another carbamate, was the least toxic (LC_{50} = 73.27 PPM). No significant heterogeneity among the insect population was present at 5% level.

The response of N. americoferus adults to treatment with the different insecticides (Table 22 and Fig. 3) also varied with LC_{50}'s ranging from 18.56 (carbofuran) to 277.13 (malathion) parts per million. Except for carbaryl, the carbamates were generally more toxic than the organophosphates to the damsel bug. Examination of the chi-square values indicated no significant heterogeneity among the insect population tested, at the 5% level.

When the response of individual insecticide on the three insects was examined, a general trend is observed (Figs. 4-9). The potato leafhoppers show more susceptibility than the tarnished plant bug and damsel bug. The only exception to this is the response of the three insects tested against carbofuran where tarnished plant bugs were more susceptible than potato leafhoppers. Data suggest that damsel bugs are more tolerant to insecticides than tarnished plant bugs and potato leafhoppers.

The relative toxicity of the insecticides to the predator, N. americoferus and the two insect pests, E. fabae and L. lineolaris were compared by deriving selectivity ratios (SR) as defined by Metcalf (1972) as the LC_{50} of the non-target organisms divided by the LC_{50} of the pest. Two sets of SR's were obtained (Table 23): (1) adults of N. americoferus vs. adults of E. fabae and (2) adults of N. americoferus vs. adults of L. lineolaris. In the predation test, the tarnished plant bug was not found to be a predator of the potato

Table 22

Median lethal concentrations of insecticides tested against *N. americoferus*.[a]

INSECTICIDE[b]	LC_{50} (PPM)	95% FIDUCIAL LIMITS	REGRESSION EQUATION	PROBABILITY > χ^2
carbofuran (C)	18.56	15.51 - 21.65	$y = 3.96 + 0.06x$	0.55
methomyl (C)	22.46	10.05 - 34.79	$y = 4.19 + 0.04x$	0.15
methidathion (OP)	79.82	70.89 - 89.55	$y = 3.64 + 0.02x$	0.50
carbaryl (C)	173.91	90.91 - 255.67	$y = 4.17 + 0.004x$	0.12
azinphosmethyl (OP)	199.46	123.08 - 280.81	$y = 3.87 + 0.006x$	0.15
malathion (OP)	273.13	237.05 - 311.86	$y = 3.93 + 0.004x$	0.56

[a] Arranged in descending order of toxicity.

[b] OP = organophosphates; C = carbamates.

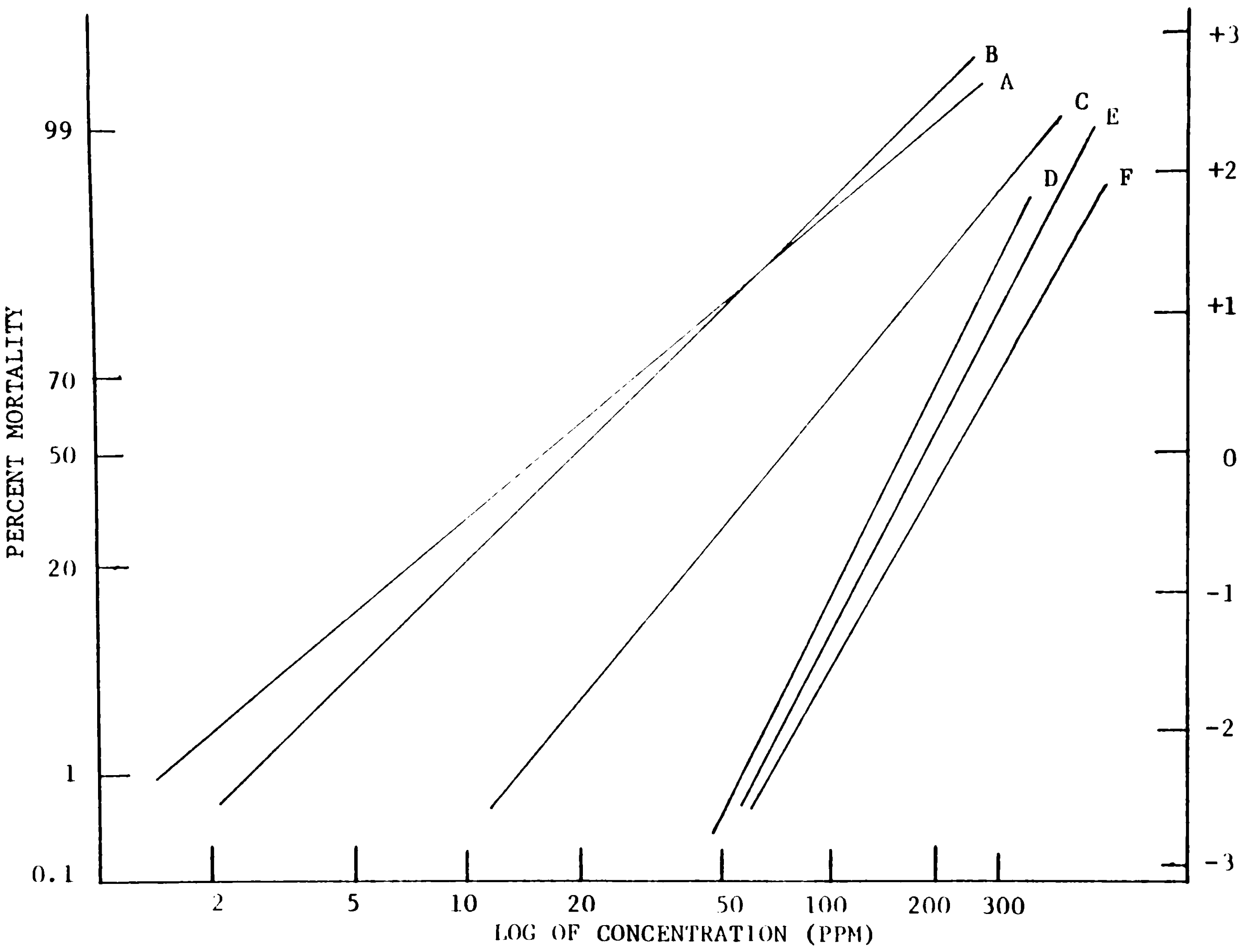

Figure 3. Response of mixed-sex populations of *N. americoferus* to insecticides.

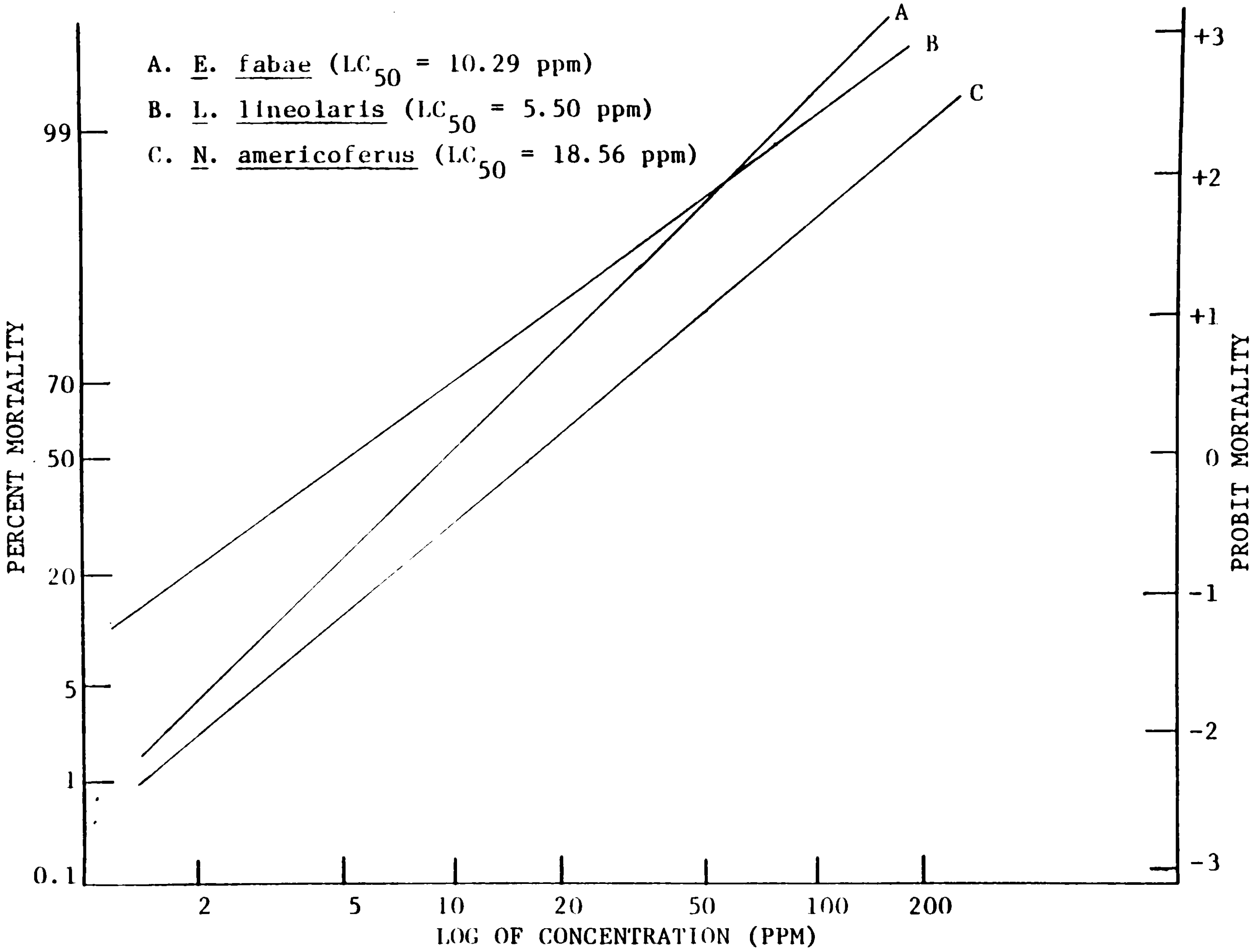

Figure 4. Response of mixed-sex populations of potato leafhoppers, tarnished plant bugs and damsel bug to carbofuran.

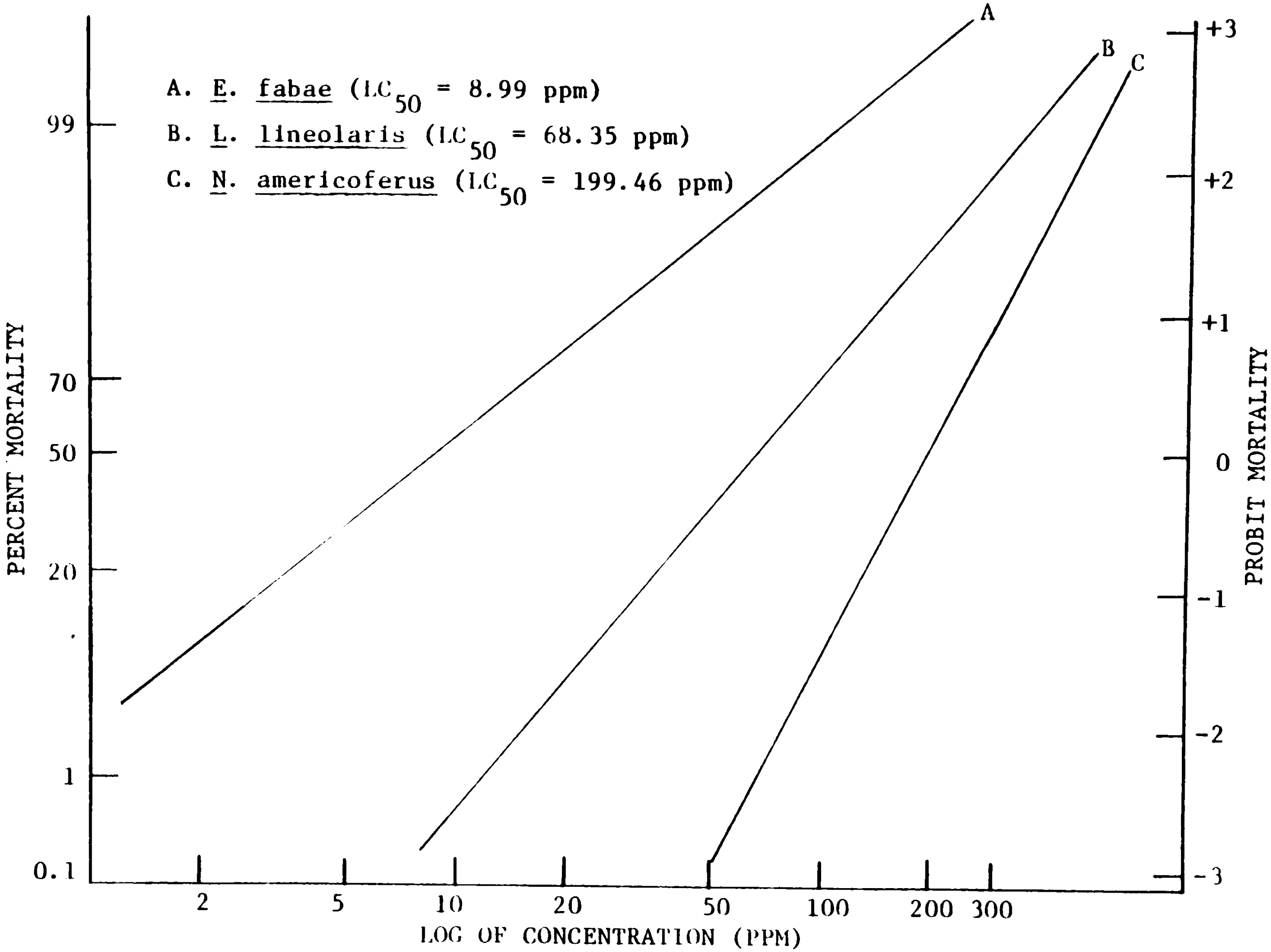

Figure 5. Response of mixed-sex populations of potato leafhoppers, tarnished plant bugs, and damsel bug to azinphosmethyl.

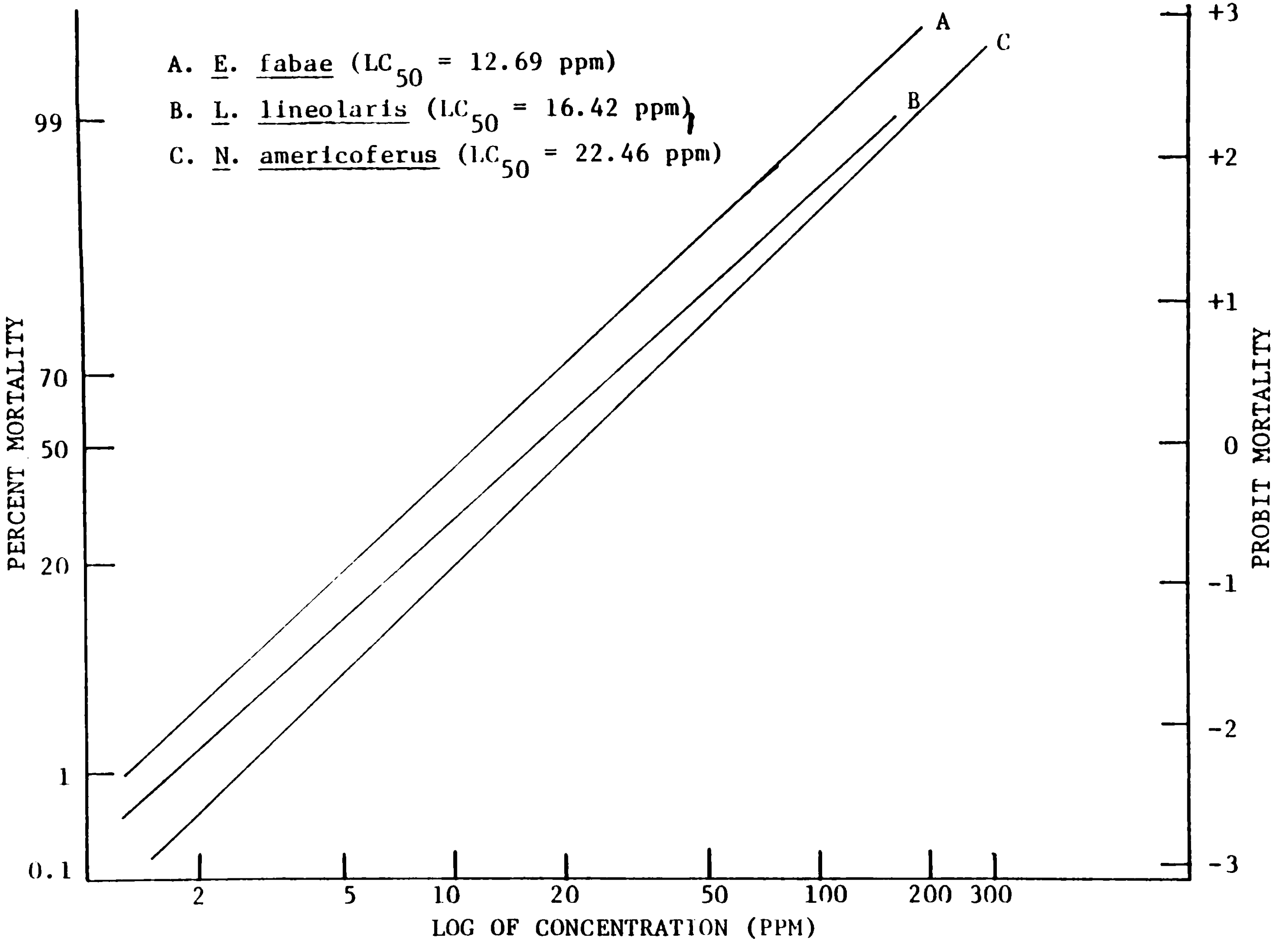

Figure 6. Response of mixed-sex populations of potato leafhoppers, tarnished plant bugs, and damsel bug to methomyl.

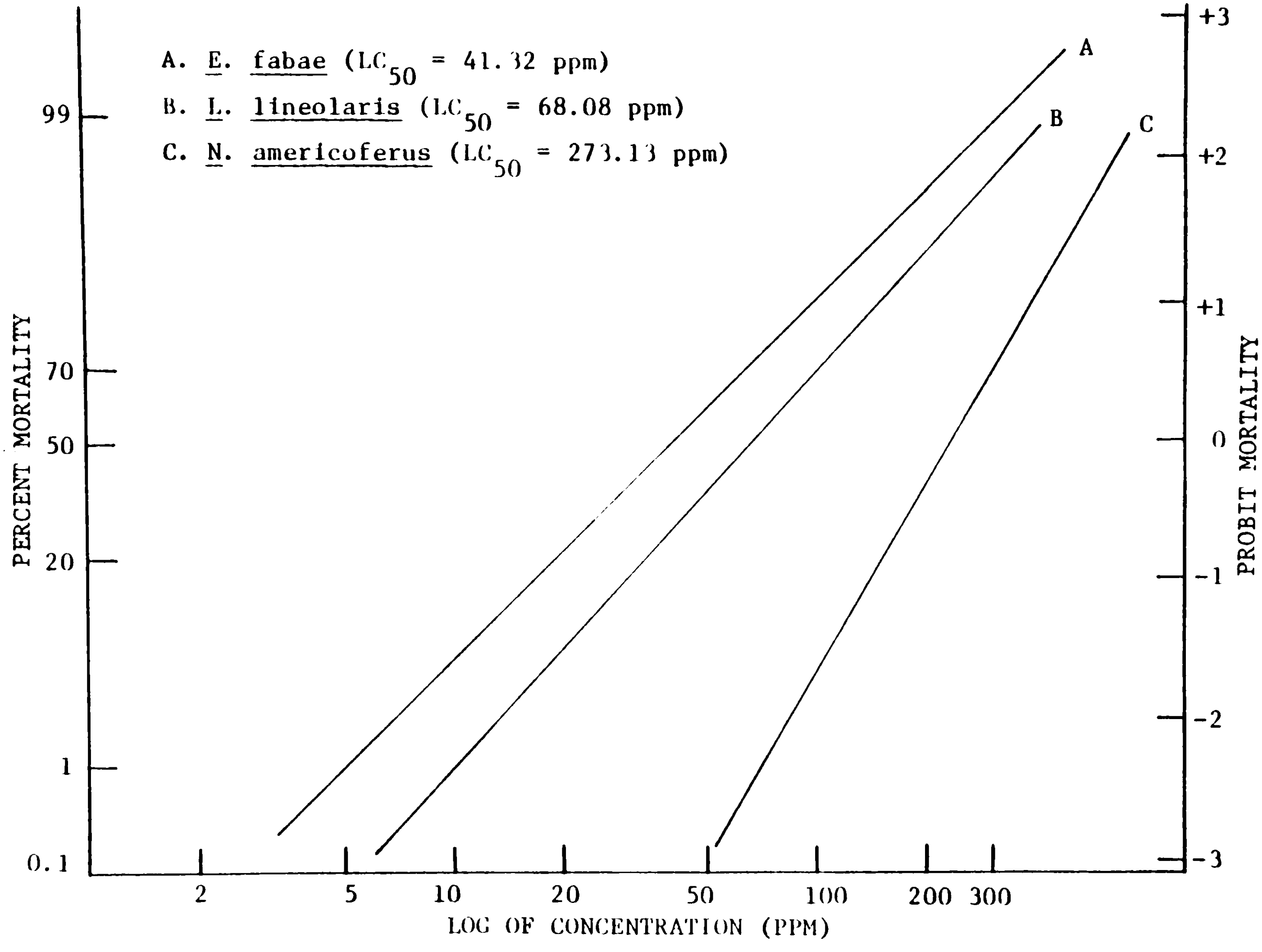

Figure 7. Response of mixed-sex populations of potato leafhoppers, tarnished plant bug, and damsel bug to malathion.

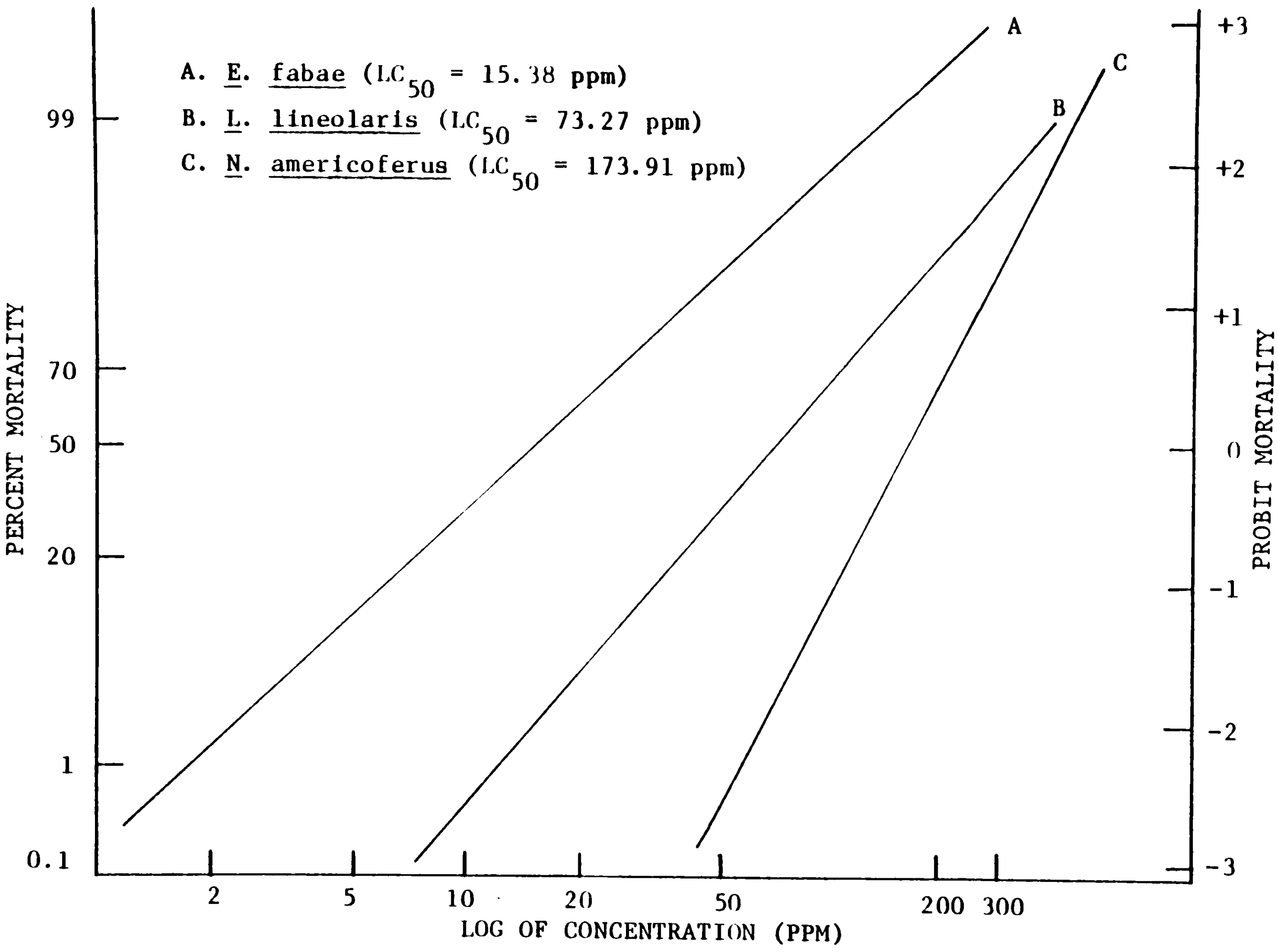

Figure 8. Response of mixed-sex populations of potato leafhoppers, tarnished plant bugs, and damsel bug to carbaryl.

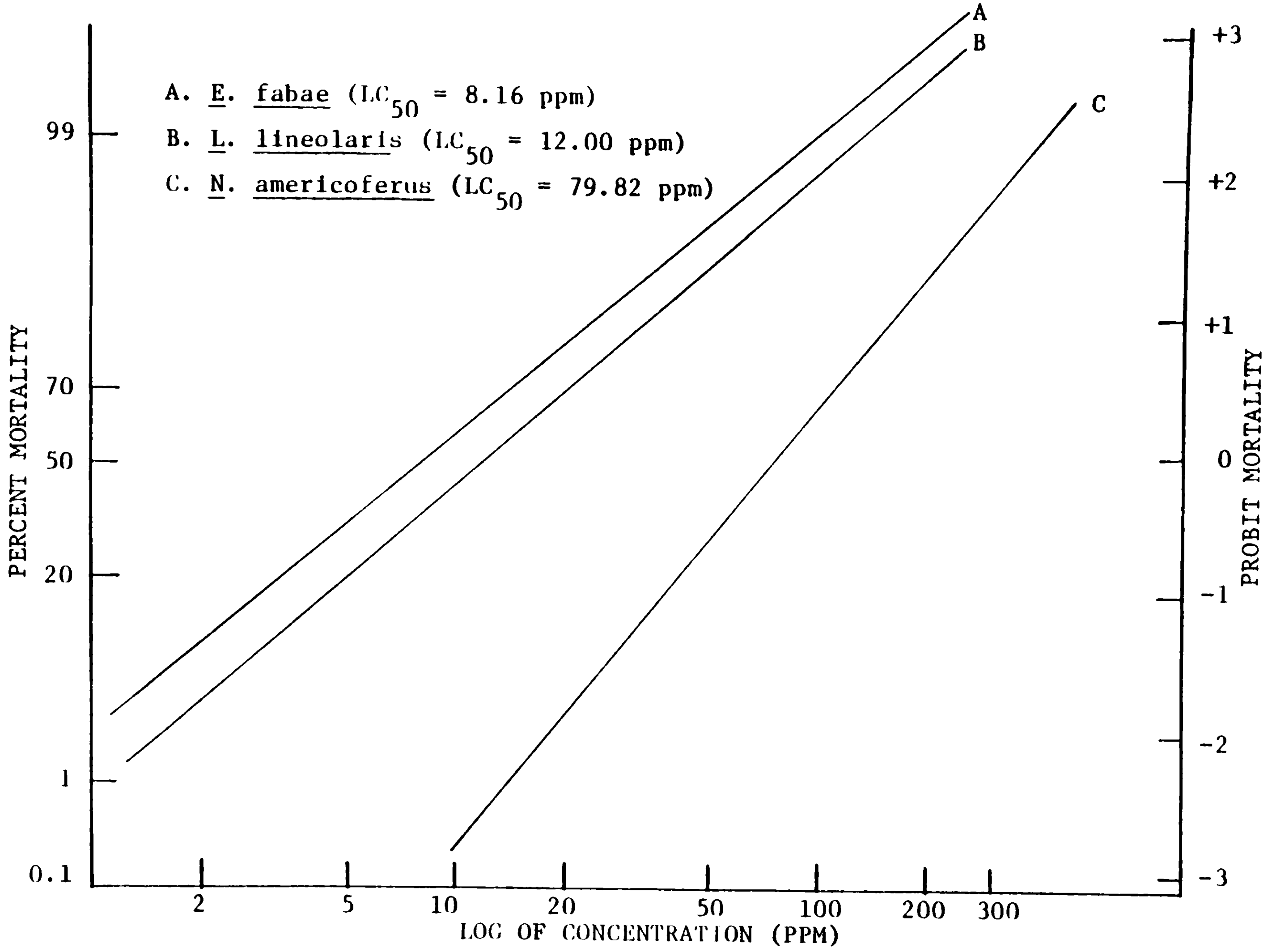

Figure 9. Response of mixed-sex populations to potato leafhoppers, tarnished plant bugs, and damsel bug to methidathion.

Table 23

Selectivity of different insecticides to *N. americoferus* against *E. fabae* and *L. lineolaris*.

INSECTICIDE	SELECTIVITY RATIO[a]	
	E. FABAE	*L. LINEOLARIS*
methidathion (OP)	9.78	6.65
azinphosmethyl (OP)	22.19	2.92
carbofuran (C)	1.80	3.37
methomyl (C)	1.77	1.37
carbaryl (C)	11.31	2.37
malathion (OP)	6.61	4.01

[a] Selectivity Ratio (SR) = LC_{50} of predator ÷ LC_{50} of host. An SR < indicates selectivity favoring the pest; an SR > 1 indicates selectivity favoring the predator.

leafhopper. Hence, the tarnished plant bug is being treated here as a pest considering that it feeds on many crops though it is not considered a serious pest of alfalfa grown for hay. An SR value of less than one indicates selectivity favoring the pest and a value of more than one represents selectivity favoring the predator.

Examination of selectivity ratios reveal that most of the insecticides are highly selective--except for methomyl and carbofuran for *E. fabae*. The data suggest that generally, the organophosphates are more selective than carbamates. Among the organophosphates, azinphosmethyl and methidathion were the most selective against *E. fabae* and *L. lineolaris* respectively. Among the carbamates, carbaryl and carbofuran were the most selective against *E. fabae* and *L. lineolaris* respectively.

The study conducted indicates that some broad-spectrum insecticides may be selective, i.e., the natural enemies of insect pests exhibit a tolerance to some insecticides that are toxic to pest insects. Ripper (1956) and Smith and van den Bosch (1968) recommended that selectivity could be enhanced by using lower doses of insecticides. Higher doses could cause mortality to the beneficial insects. However, Bartlett (1963) pointed out that such a toxicant must have a broad pattern of tolerance lest the gains made on one parasite or predator be lost with others.

Croft and Brown (1975) have deduced from 20 published investigations the toxicities to 10 species of coccinellids. When the insecticides were arranged into 5 classes of descending toxicity, malathion, azinphosmethyl, and carbaryl were rated most toxic.

Earlier studies by van den Bosch et al. (1956) indicated that *Chrysopa* are generally less susceptible to insecticides. This observation has also been made by Bartlett (1964) and Lingren and Ridgway (1967). Plapp and Bull (1978) reported that most organophosphates and the carbamate methomyl were highly toxic to *C. carnea*. However, carbaryl, several pyrethroids, and organochlorines were much less toxic to *C. carnea*.

In assessing the direct toxicity of insecticides to natural enemies, the influence of environmental and physiological factors affecting susceptibility should also be studied. Environmental factors such as temperature, moisture, soil pH and compaction, and illumination could have an important influence on the breakdown of chemicals. Physiological factors such as age or stage of insects, and nutritional status should also be considered in the overall studies. While all the factors mentioned above could play roles on direct toxicities of insecticides, their relation to selectivity is vague. Finally, attention should be focused in attempting to explain more fully whether any physiological and environmental differences exist between arthropod natural enemies and pest arthropods in their responses to insecticides.

VI. SUMMARY

Selected insecticides were evaluated to determine effects on the potato leafhopper and its predators. Three types of tests were conducted. First, the common predators of the potato leafhopper in alfalfa were examined to determine their response to the stages of the leafhopper. Second, under field conditions, insecticides were tested to detect effects on the populations of the insects. Finally, LC_{50} toxicities of selected insecticides were investigated under laboratory conditions.

In the predation tests, two studies were conducted, namely, predation on egg stage and predation on nymphal and adult stages of the potato leafhopper. An indirect method of determining egg predation was employed because potato leafhopper eggs are not visible, being concealed in the xylem and phloem tissues. Using two sets of treatments (with and without predators), the potato leafhopper females were allowed to oviposit in predation cages and the suspected predators introduced thereafter. Hatching nymphs were counted and used as indications of the number of eggs laid. Nabis americoferus and Orius insidiosis were found to be predaceous on eggs of the potato leafhopper. In the predation tests, using nymphal and adult stages of the potato leafhopper, the following adult and larval stages of insects were confirmed as predators: Hippodamia convergens, Coccinella novemnotata, and Chrysopa carnea.

Two field tests, one in summer of 1977 and one in summer of 1978, were conducted to determine the influence of insecticides on populations of potato leafhoppers and its predators in alfalfa. Samples were taken using a 38 cm sweep net employing a 180° motion at 2 days, 1 week, and 2 weeks after treatment. In both tests, significant control was provided by the chemicals against potato leafhoppers 48 hours following application. A gradual population recovery occurred one week and two weeks after treatment. Most of the entomophagous insects sampled were adversely affected by insecticides. No statistical differences in yield and percent dry matter were obtained with various insecticidal treatments.

The acute toxicities of selected insecticides on potato leafhopper, tarnished plant bug, and damsel bug were investigated. The bioassay method used was the immersion technique and toxicity was expressed in LC_{50}. The relative toxicities of *Nabis americoferus* to *Empoasca fabae* and *Lygus lineolaris* were obtained by deriving the selectivity ratios. Selectivity ratios are calculated by dividing the LC_{50} of the non-target organism divided by the LC_{50} of the pest. The ratios indicated that most of the insecticides tested were highly selective. Among the organophosphates, azinphosmethyl was the most selective, while among the carbamates, carbaryl was the most selective.

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VIII. VITA

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EFFECTS OF INSECTICIDES ON POTATO LEAFHOPPERS, *EMPOASCA FABAE* (HARRIS) AND ITS PREDATORS

by

Danilo G. Martinez

(ABSTRACT)

The potato leafhopper is one of the major pests of alfalfa in Virginia. Control practices against this pest include various methods which could be incorporated into an integrated pest management program. In the past, chemicals have provided the primary method of control of the potato leafhopper. With the growing pressures for environmentally safe pest management practices, studies were performed to determine effects of chemicals on target and non-target organisms.

Common entomophagous species of insects in alfalfa were collected and tested for predation on the potato leafhopper. *Nabis americoferus* and *Orius insidiosis* adults were found to prey on eggs of potato leafhopper using an indirect method. The adult and larval stages of *Hippodamia convergens*, *Coccinella novemnotata*, and *Chrysopa carnea* were also found to be predators of the nymphal and adult stages of the potato leafhopper.

Field tests were conducted to determine the influence of insecticides on populations of potato leafhoppers and its predators. While the population of most predators were adversely affected, significant control of leafhoppers were obtained.

Acute toxicities of selected insecticides on potato leafhoppers, tarnished plant bug, and damsel bug were investigated. Selectivity ratios indicated that most of the chemicals tested were selective in favor of the predators.